Fermilab
ES&H Section

R.P. NOTE 150

SUMMARY OF CY 2004 TOTAL EFFECTIVE DOSE EQUIVALENT

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1. OVERVIEW

The mission of Fermi National Accelerator Laboratory is to advance the understanding of the fundamental nature of matter and energy by conducting research at the frontier of high energy physics. Today this involves producing and accelerating the largest numbers of protons ever recorded in the history of the Laboratory in order to achieve the sensitivities needed to resolve the important scientific questions under investigation. This demand for increased intensity and luminosity is necessary to support both collider physics experiments that are operating at the current energy frontier, as well as neutrino physics experiments that require unprecedented beam intensities. However, the ability to deliver even larger numbers of high energy protons is limited by activation and radiation damage to accelerator components. Maintenance activities to repair such components have been shown to lead to radiation doses to personnel. Cossairt has analyzed historic trends in radiation exposures at Fermilab.[1] The purpose of this paper is to analyze the dosimetry results for CY04 in the context of the overall Fermilab operational program.

At Fermilab, along with most large particle accelerators worldwide, the majority of radiation exposure is received from maintenance activities conducted with the beam turned off. This was demonstrated in RP Note 148, "*Summary of CY 2003 Total Effective Dose Equivalent*".[2] At Fermilab essentially no personnel exposure is due to prompt radiation fields present with the accelerator turned on due to well-designed bulk shielding and extremely effective implementation of radiation safety interlocks. As an important part of normal operation of the Tevatron Collider program and the neutrino physics experiments, MiniBooNE and a new facility, NuMI/MINOS, the Laboratory must conduct periodic major shutdowns to maintain and repair existing equipment and upgrade older beam line components to meet the goal of higher beam intensities. The Laboratory also took advantage of the latest shutdown to complete the installation of the NuMI beam line. While improved accelerator performance is the primary goal of these shutdowns, the reduction of future radiation exposures through better component design and improved reliability was viewed by all personnel involved as being of singular importance. It was recognized by all involved that improvements to the accelerators necessary to meet programmatic goals would require some additional worker exposures compared with those experienced in recent years. Thus, the careful planning of the requisite work tasks is given considerable scrutiny in order to maintain personnel radiation exposures as low as reasonably achievable (ALARA) in accordance with overall implementation of Fermilab's Integrated Safety Management (ISM) program.

2. Description of Major Shutdown Tasks

During calendar year 2004 there was one major 13 week shutdown that began on August 23rd. There was also a brief maintenance shutdown period that was scheduled to last approximately 10 days during March. This "minor" shutdown was necessary to correct vacuum leakage problems in the Tevatron. The majority of the work performed during these shutdown periods involved Accelerator Division personnel, although personnel from other divisions/sections assisted as necessary. These individuals were fully trained in radiological work procedures in general and were thoroughly briefed in the specifics of each job task. The 13 week shutdown involved several major projects, specifically, the installation of electron cooling in the Recycler, installation of a new focusing horn for the MiniBooNE experiment, several upgrades and component replacement in the Booster and the completion of the NuMI beam line installation. All of these tasks were necessary to achieve the challenging goals of the physics research program, while at the same time were aimed at reducing beam losses, which is an essential ingredient in improving performance and increasing deliverable proton intensities. Reducing beam losses also reduces radioactivation of beam line components and potential radiation dose to personnel who must maintain the accelerators in the future.

A brief summary of major shutdown activities, is provided below. The intent of these summaries is to supply the reader with some idea of how this body of work fits into the overall goals of improved accelerator performance, enhanced reliability, and better control of present, and future, radiation exposures.

Electron Cooling Project

Electron Cooling is a project aimed at increasing proton-antiproton collisions in the Tevatron Collider by establishing electron cooling of antiprotons in the Fermilab Recycler permanent magnet storage ring. The electrons will be provided by a pelletron accelerator and an associated beam line that has previously been used "off-line" in a test configuration. During cooling operations, longitudinal and transverse momentum spread of the stored antiprotons will be reduced by transferring this momentum spread to the much less massive electrons from the pellatron traveling alongside the antiproton beam at the same velocity through a short, specialized section of the Recycler ring. During the fall shutdown, the pelletron and its associated beam line was reassembled in the Recycler in preparation for commissioning electron cooling in the near future. The shutdown work focused on the section that runs through the Main Injector (MI) tunnel. It contains 10 electron-cooling tanks with solenoids, in which a continuous beam of electrons will mix with a stream of antiprotons. Below the cooling section is a new beam line through which the electrons travel back to their source, the pelletron in the MI-31 building adjacent to the MI tunnel.

Booster

Once again, the Booster was a primary focus of the 2004 fall shutdown. Previous experience and recent measurements indicate that the Booster has been the location of the majority of proton beam loss. The shutdown goal for the Booster was to increase the number of protons that the machine can accelerate per cycle, while reducing beam losses. Part of this work consisted of removing old, relatively highly activated beam line equipment and installing an additional RF cavity in the Booster. The new cavity has a larger aperture that will reduce beam loss, preventing the cavity from becoming as highly activated. The other jobs consisted of magnet replacement and reconfiguration at Long 13. Two dogleg magnets, along with magnets ML01 and MP01 were replaced in that area. This was done to improve machine performance and enhance machine reliability, which will lead to lower beam losses in the future as intensity demands increase. Water tubing replacement work occurred at four locations in the Booster lattice. The previous plastic tubing and orange "garden" hoses were replaced with PEEK tubing. This work was also done to increase machine reliability and thus decrease the radiation exposure to technicians. PEEK tubing is more tolerant of the high radiation levels present during operations. The Booster jobs also included beam positioning monitor (BPM) replacement at two separate locations.

MiniBooNE

The MiniBooNE horn, a beam focusing device, after two years of flawless operation, began malfunctioning. This was exhibited by water leaks and electrical faults. So, the task of its replacement was added to the list of shutdown jobs. Using specifically developed safety procedures and documented dry runs, a very detailed ALARA plan was developed covering both the removal and replacement of the horn. The old horn was placed in a doubly shielded (5" thick iron) coffin, removed from its location and transferred to a well-shielded storage location. The removal procedure contained 128 distinct steps. Critical safety factors addressed the spatial confinement in the experimental hall and the 20-ton lifting capacities of the cranes at the removal and storage locations. The new horn was modified to avoid some of the water-leakage and ground-fault problems that eventually affected the original. The failure of the original horn is not considered a major disappointment since it produced a world record of 96 million pulses.

NuMI

The NuMI work in the Main Injector tunnel consisted of finishing all installation work, alignment, vacuum hookup plus the testing of devices before the end of the shutdown. The NuMI project devoted the last week of the shutdown to test all devices installed during the shutdown, checking the accuracy of magnetic fields and "exercising" instrumentation. The testing will minimize access time to the tunnel when the Main Injector is back in operation. The NuMI beam line is ready for testing and commissioning. The beam line has many components, and the commissioning plan calls for several weeks of testing and measurements on the way to routine high intensity operations. As a result of schedules being kept, the first proton beam was transported down the NuMI Beam line on December 3, 2004, and the MINOS experimenters will soon be ready to begin observing neutrino events.

3. Radiation Monitoring /Dose Results

While the Laboratory pursues increased beam intensities, it continues to diligently manage a Radiation Protection Program as part of ISM to control radiation doses to personnel and keep exposures ALARA. The quarterly reported TLD dose results indicate that over the past few years the doses received by personnel are decreasing with time as the proton numbers increase during routine accelerator operations.[2] However, as was shown in the personnel dose summary for CY 03, necessary shutdowns of the accelerators for upgrades, maintenance and repair work may lead to an increase in the TEDE. The results for CY 04, are shown in Table 1. The TEDE for CY 04 is 20.13 person-rem, which is about a 5 person-rem decrease from CY 03. The first, third and fourth quarter TEDE all reflect shutdown activities. Table 2 shows that once again there were more individual doses in the 10-20 mrem range and a few higher doses that are not present during routine accelerator operations. It should be emphasized that overall doses to individuals still remain generally low compared to levels of regulatory concern or with natural background levels. In the future, routine accelerator operations will include both the Collider Experiments and the Neutrino Physics experiments at higher Booster and Main Injector intensities, which will most likely result in different personnel dose trends. Personnel doses will continue to be monitored and re-evaluated as a result of these new operating conditions.

Figure 1 shows the dose distribution by quarter for CY 2002, 2003 and 2004 for Fermilab as a whole and for the Accelerator and Particle Physics Divisions whose personnel carried out the vast majority of the shutdown tasks.

The Accelerator Division is again recognized for efforts made to keep doses received by personnel performing shutdown tasks as low as reasonably achievable (ALARA). An important component of this effort was the conduct of job-specific ALARA planning for each major task. Also, some tasks that were likely to be "high dose" were deferred to the latter portion of the shutdown in order to take advantage of radioactive decay to reduce the radiation levels involved. The job-planning efforts included detailed estimates of the individual doses associated with subtasks. During the work, supplementary dosimeter readings were recorded on a daily basis. The dose predictions were quite accurate as verified by these supplementary dosimeter readings. The supplementary dosimeter results were also in good agreement with the results measured by the DOELAP-accredited dosimeter badges, received at a later time following each quarterly badging period. Although these improvement projects, once again, did have an impact on the TEDE during CY 2004, the long term benefits will prove invaluable for accelerator performance and dose reduction in the future. Thus, an investment has been made in future improved operations with radiation exposures maintained ALARA.

References:

1. J.D. Cossairt, 2003, RP Note 142, *Long Term Trends in Radiation Exposures at Fermilab.*

2. S. McGimpsey 2004, RP Note 148, *Summary of CY 2003 Total Effective Dose Equivalent*

Table 1

Quarterly TEDE Results for CY 2003 and CY 2004

	CY 2003	CY 2004
	Person-rem	Person-rem
1st Quarter	8.48*	5.54*
2nd Quarter	3.46	2.10
3rd Quarter	6.50*	6.93*
4th Quarter	6.84*	5.61*
YEARLY TOTAL	25.28	20.18

* Quarters that involve shutdown activities

Table 2

Distribution of Individual Doses in CY 2004

Dose Range (mrem)	1st Qtr 2004 Number of Doses	2nd Qtr 2004 Number of Doses	3rd Qtr 2004 Number of Doses	4th Qtr 2004 Number of Doses	Total # of Reportable Doses
10 - 20	190	106	200	136	
30 - 40	27	9	34	18	
50 - 60	12	3	10	13	
70 - 80	6	3	11	10	
90 - 100	6	1	10	7	
> 100	4	0	6	8	
Highest Dose	150	90	180	210	
					830

Table 3

Distribution of Individual Doses in CY 2003

Dose Range (mrem)	1st Qtr 2003 Number of Doses	2nd Qtr 2003 Number of Doses	3rd Qtr 2003 Number of Doses	4th Qtr 2003 Number of Doses	Total # of Reportable Doses
10 - 20	236	147	251	102	
30 - 40	43	23	24	43	
50 - 60	17	5	11	21	
70 - 80	9	1	6	5	
90 - 100	6	4	5	5	
> 100	10	0	6	5	
Highest Dose	280	100	230	270	
					985

Figure 1

TEDE Results for Fermilab, Accelerator Division, and Particle Physics Division